THYRISTORS

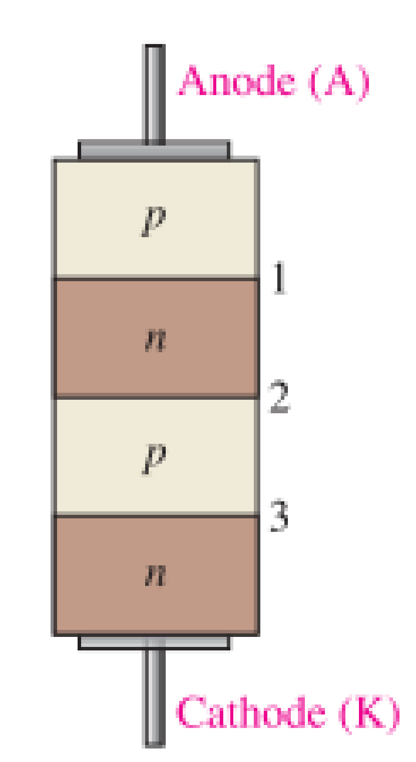
Lecture 7

OVERVIEW

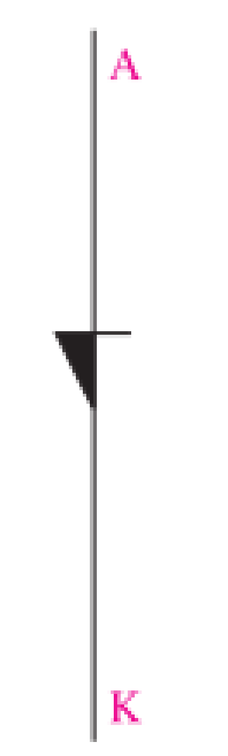
- Basic structure of Thyristor
- Working principles of Thyristor
- Forward Breakover Voltage
- Holding and switching current
- The Silicon-Controlled Rectifier (SCR).
- SCR Characteristics and Rating
- SCR Applications

BASIC STRUCTURE

- **Definition**: The device acts as a switch and remains off until the forward voltage reaches a certain value; then it turns on and conducts. Conduction continues until the current is reduced below a specified value.
- **Basics**:
  - Two terminals: Anode & Cathode
  - 4-layer device (4 semiconductor layers)
  - ***pnpn*** structure
  - Three ***pn*** junction
  - Known as **Shokley** diode & SUS (Silicon Unilateral Switch)



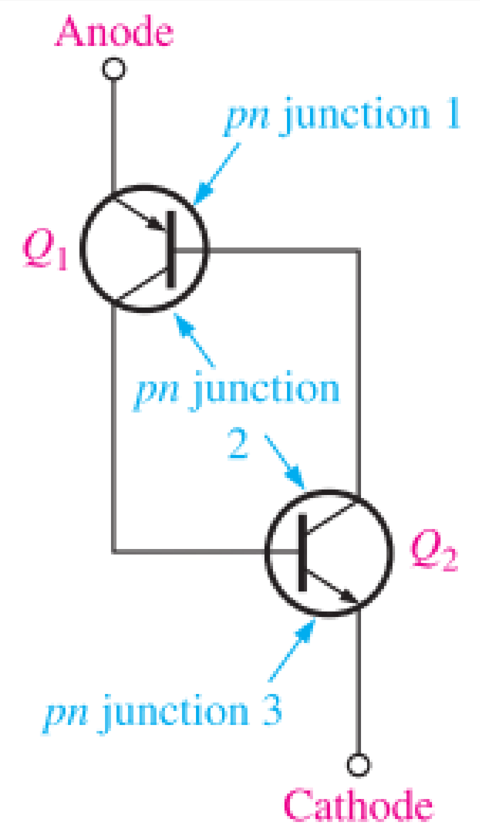
Schematic symbol

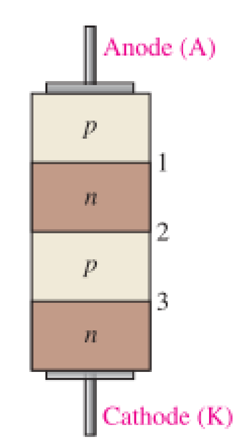


Schematic symbol

BASIC STRUCTURE

- Tyristor equivalent circuit::
  - ***pnp*** and ***npn*** transistors
  - Upper ***pnp*** layer as Q_1 and lower ***npn*** layer from Q_2
  - Middle layer shared by both transistors

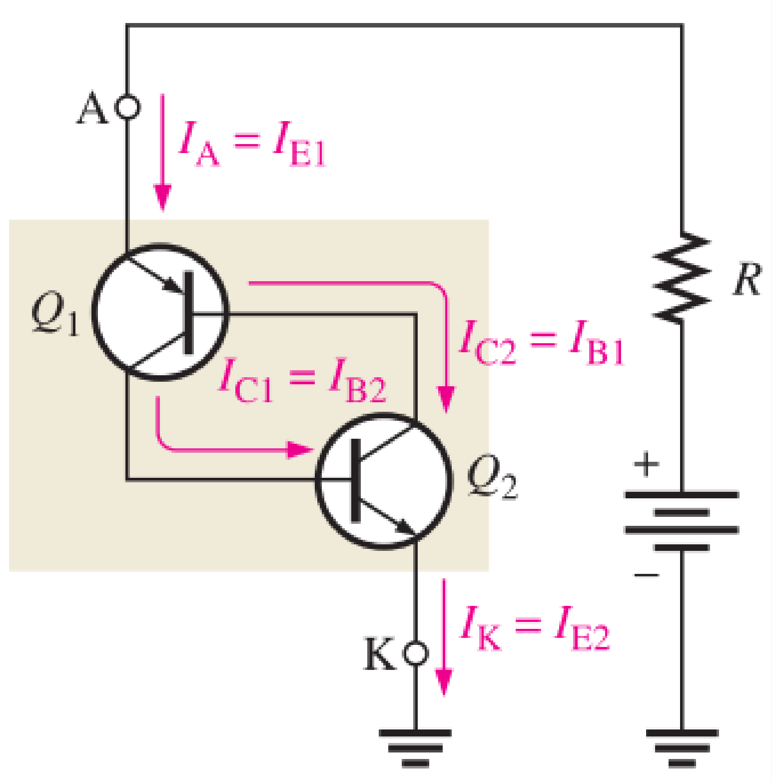


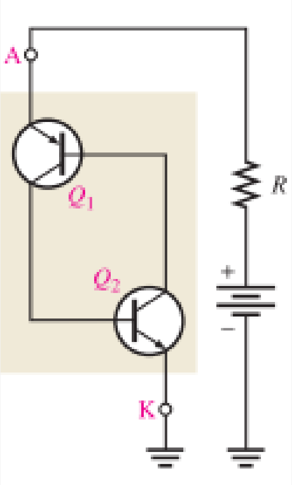


WORKING PRINCIPLE

Positive bias voltage applied to the anode with respect to cathode

- The base-emitter junction Q_1 & Q_2 are forward-biased
- Common base-collector junction (***pn***) is reverse-biased
- At low-bias level → Anode current is little → It is in the **OFF** state or forward-blocking region

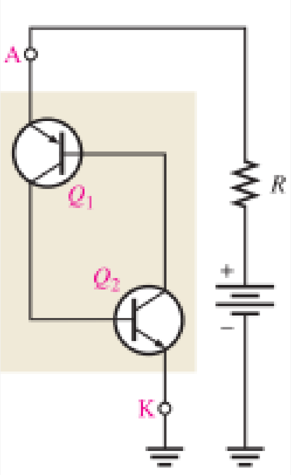


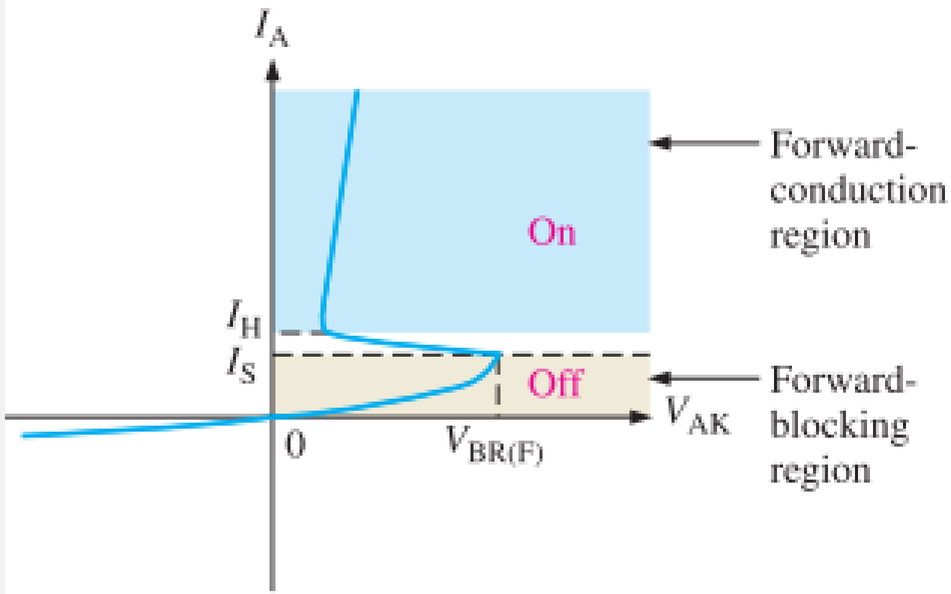


FORWARD-BREAKOVER VOLTAGE

- Forward-blocking region (forward bias):
  - Device has a very high forward resistance (ideally an open)
  - Device is in **OFF** state, acts as an open switch
  - Exist from: $V_{AK} = 0\ V$ to value $V_{AK} = V_{BR(F)}$ (*called forward-breakover voltage*)
  - As V_{AK} is increased → Anode current I_A gradually increases.
  - When I_A reaches I_S (Switching current) → $V_{AK} = V_{BR(F)}$

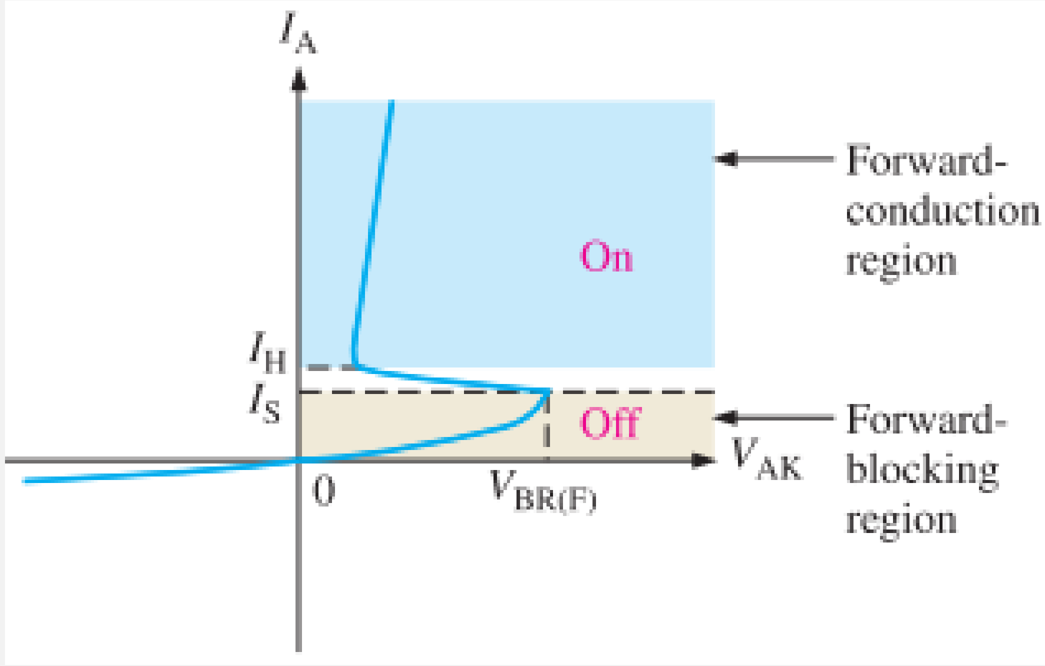
- Forward-conduction region:
  - When internal transistor structures become saturated, V_{AK} suddenly decreases to low value
  - The device is **ON** state and acts as a closed switch





HOLDING AND SWITCHING CURRENT

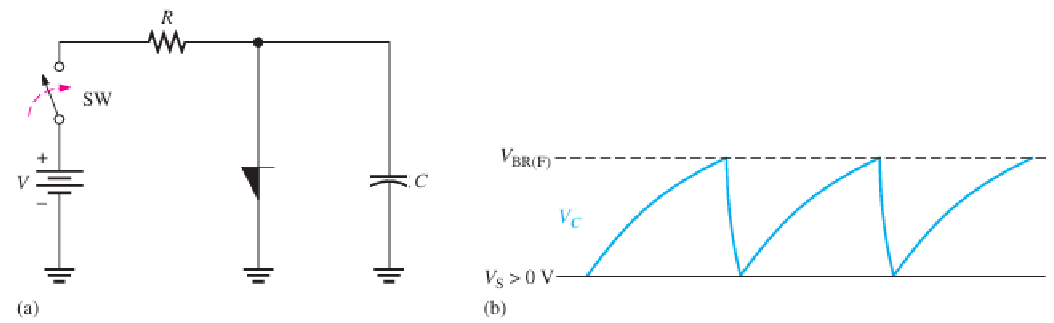
- Holding Current (I_H)
  - When the 4-layer diode (Thyristor) in in the ***ON*** state, conduction continues till anode current is reduced below a specified level, called holding current "$\boldsymbol{I_H}$"
  - Device switches to ***OFF*** state and enters the forward-blocking region, once I_A falls below I_H.
- Switching current (I_S)
  - Anode current value where the device switches from the forward-blocking-region (***OFF***) to the forward-conduction region (***ON***)
  - The value is always less than the holding current (I_H)



SHOCKLEY DIODE APPLICATION

Relaxation oscillator

- When the switch is closed, the capacitor charges through *R* until its voltage reaches the forward breakover voltage of the 4-layer diode.
- When voltage reaches $V_{BR(F)}$, the diode switches into conduction, and the capacitor rapidly discharges through the diode.
- Discharging continues until the current through the diode falls below the holding value.
- Once the current becomes below the holding value, the diode switches back to the ***OFF*** state, and the capacitor begins to charge again.

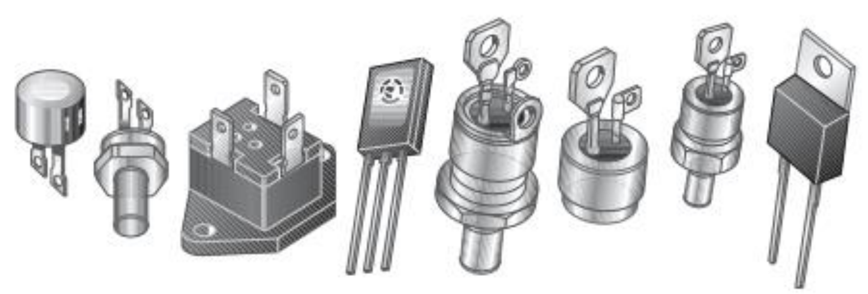


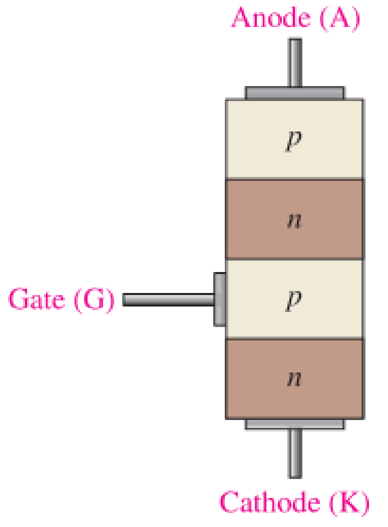
▲ FIGURE 11–6

A 4-layer diode relaxation oscillator.

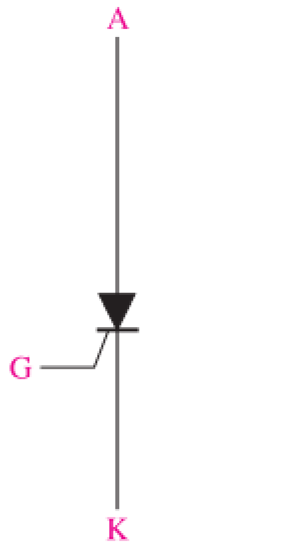
SCR
(SILICON-CONTROLLED RECTIFIER)

- Three terminals:
  - Anode, Cathode, Gate
- Has two possible states of operation:
  - ***OFF*** state:
    - Acts as open circuit between anode & cathode
    - High resistance
  - ***ON*** state:
    - Acts ideally as a short from the anode to the cathode
    - Small on (forward) resistance





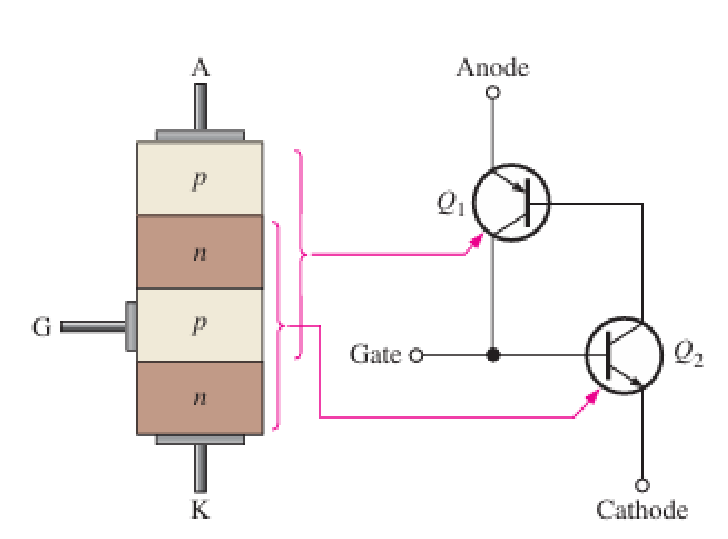
(a) Basic construction



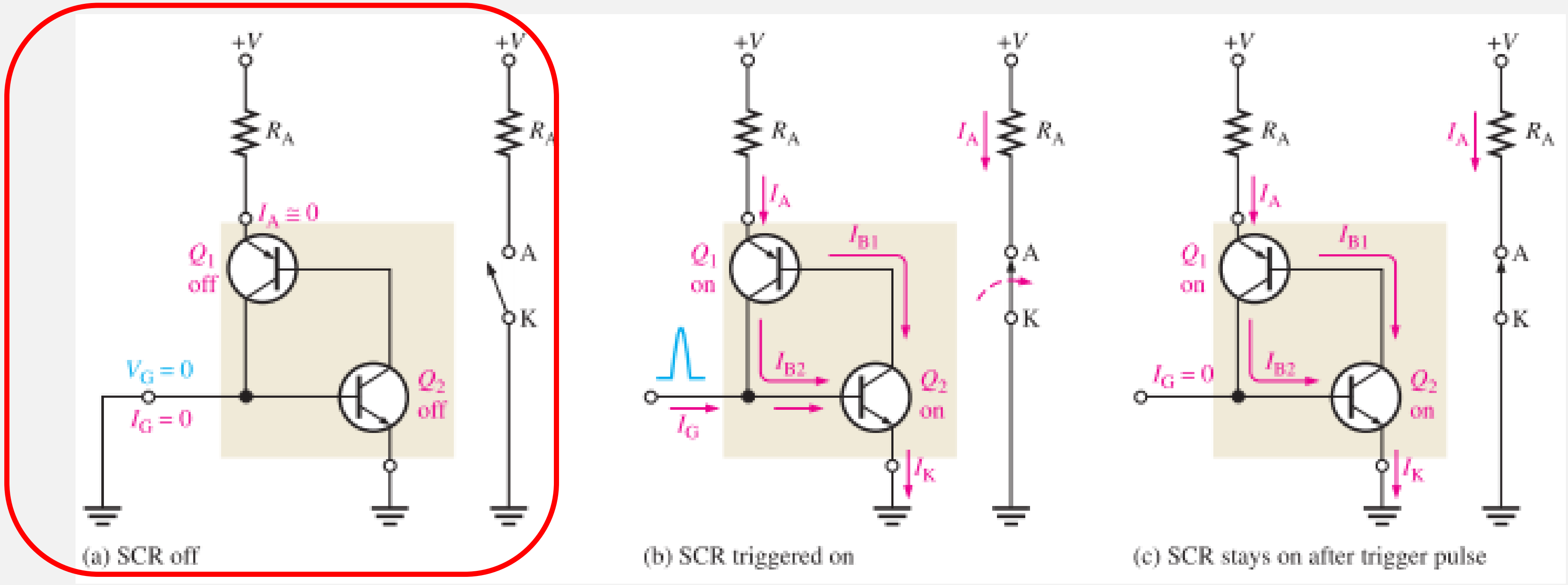
(b) Schematic symbol

SCR EQUIVALENT CIRCUIT

- 4-layer diode except for the gate connection
- The upper ***pnp*** layers act as a transistor, Q_1
- The lower ***npn*** layers act as a transistor, Q_2
- Two middle layers are “shared”

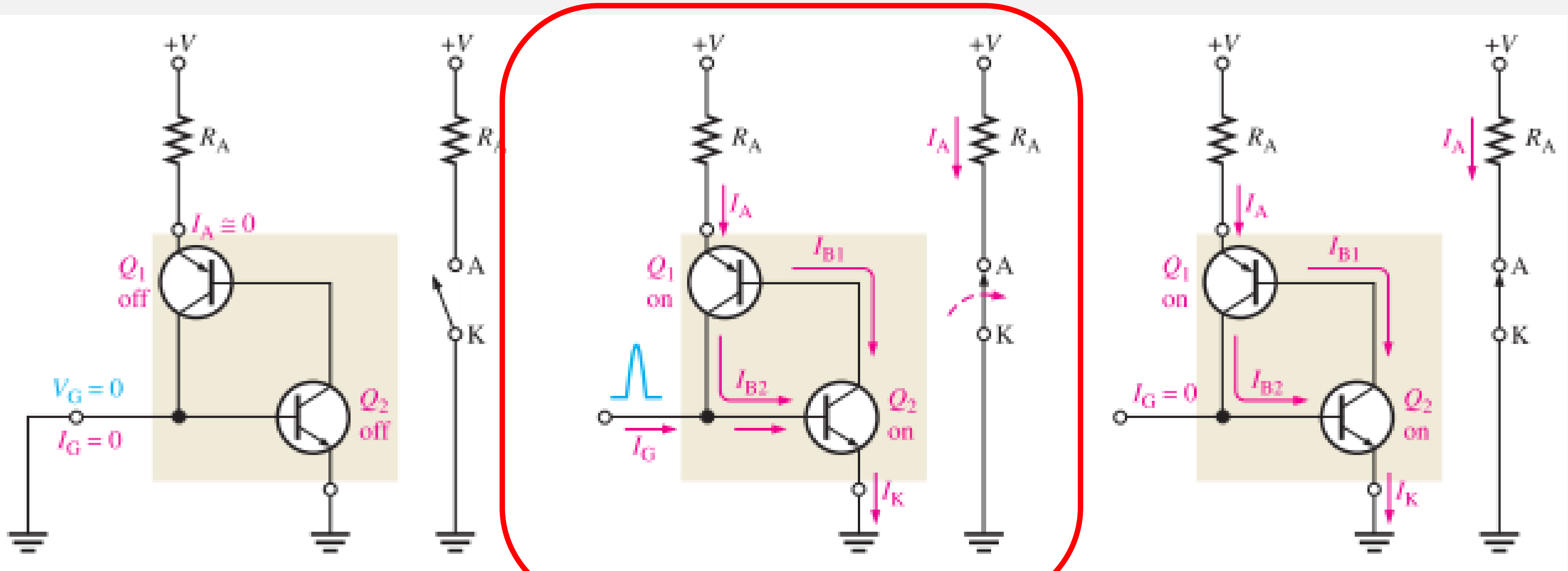


SCR "OFF" STATE



- ❖ Gate current, I_G, is zero.
- ❖ The device acts as a 4-layer diode in the ***OFF*** state
- ❖ Very high resistance between anode and cathode

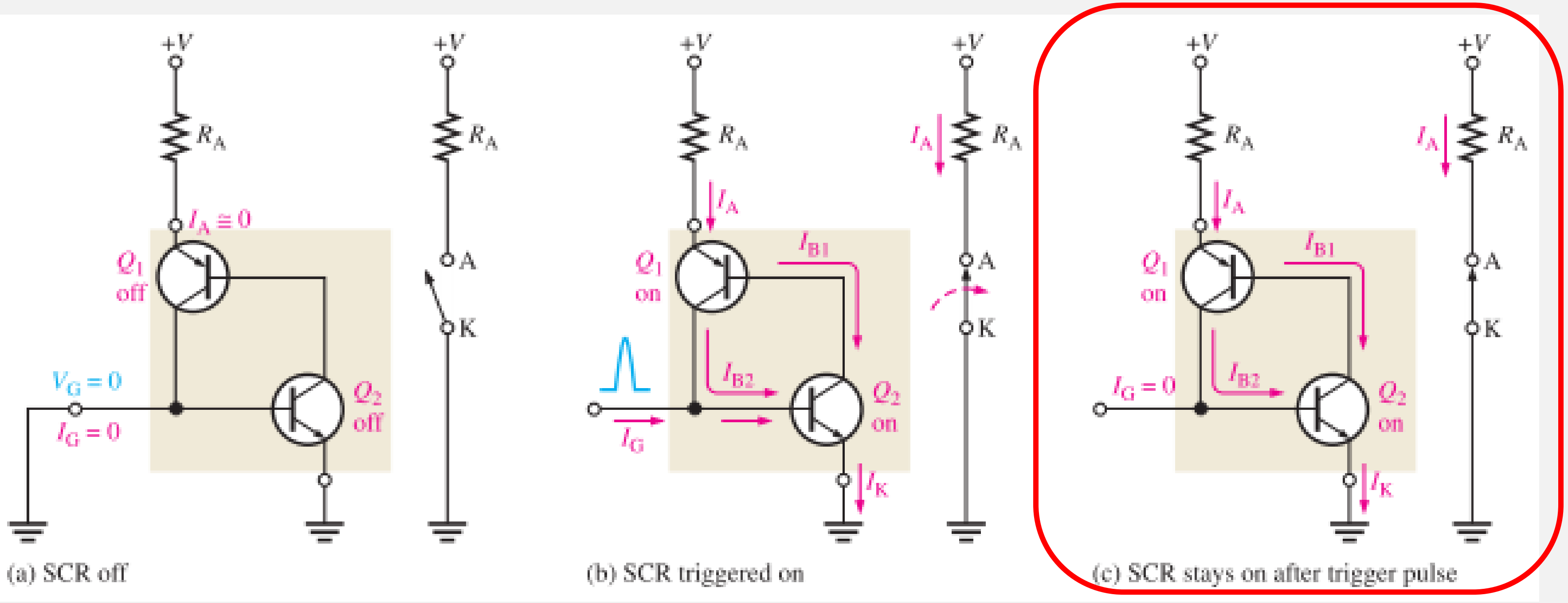
SCR "ON" STATE



(a) SCR off (b) SCR triggered on (c) SCR stays on after trigger pulse

- Positive pulse of current (trigger) is applied to the gate
- Both transistors, Q_1 and Q_2 are ***ON***
- I_{B2} turns on Q_2 → provides path for I_{B1}, thus turning on Q_1
- Q_1 collector's current provides additional base current for Q_2

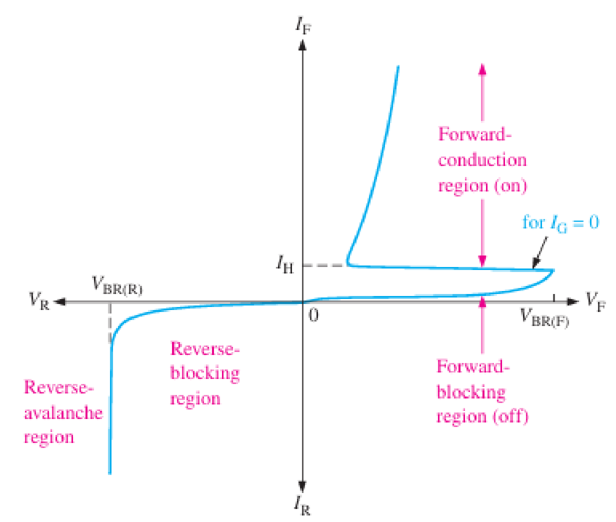
SCR AFTER TRIGGER PULSE



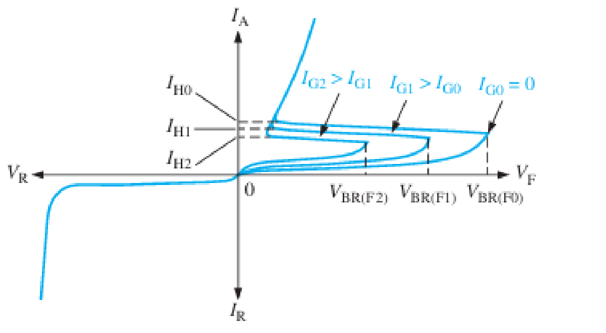
- Q_2 stays in conduction after trigger pulse is removed from the gate
- Low resistance between Anode and Cathode
- Q_2 sustains the saturated conduction of Q_1 by providing path for I_{B1}
- Q_1sustains the saturated conduction of Q_2 by providing path for I_{B2}
- Thus, the device stays on (latches) once it is triggered on

SCR CHARACTERISTIC CURVES

- An SCR can also be turned on without gate triggering by increasing the anode-to-cathode voltage to a value exceeding the forward-breakover voltage $V_{BR(F)}$.
- The forward-breakover voltage decreases as I_G is increased above 0 A.
- Eventually, a value of I_G is reached at which the SCR turns on at a very low anode-to-cathode voltage.
- The gate current controls the value of forward breakover voltage, $V_{BR(F)}$, required for turn-on.



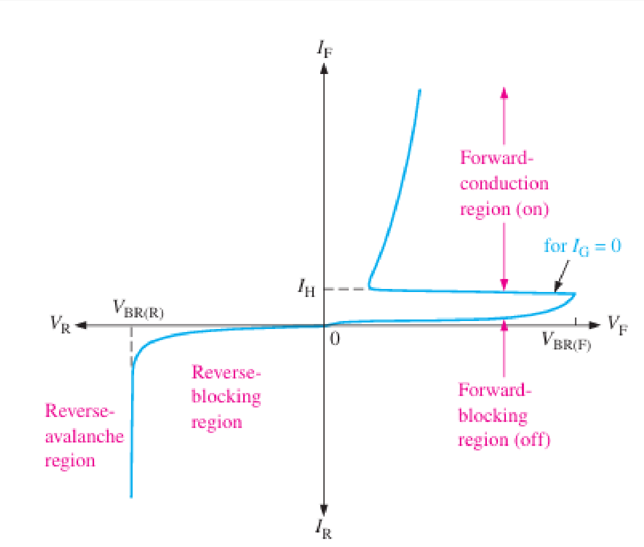
(a) For $I_G = 0$



(b) For various I_G values

TURNING THE SCR OFF

- Turning SCR off → Dropping the Anode current below the holding current (I_H)
- When the gate returns to 0V after the trigger pulse is removed, the SCR cannot turn off; it stays in the forward-conduction region.
- Two basic methods for turning off the SCR:
  1. Anode current interruption
  2. Forced commutation

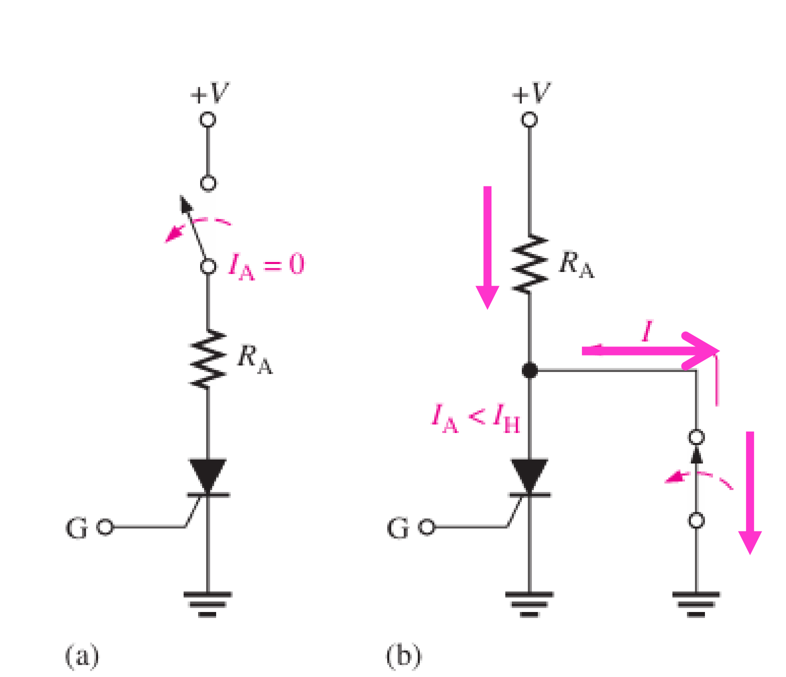


(a) For $I_G = 0$

TURNING THE SCR OFF

Anode current interruption:

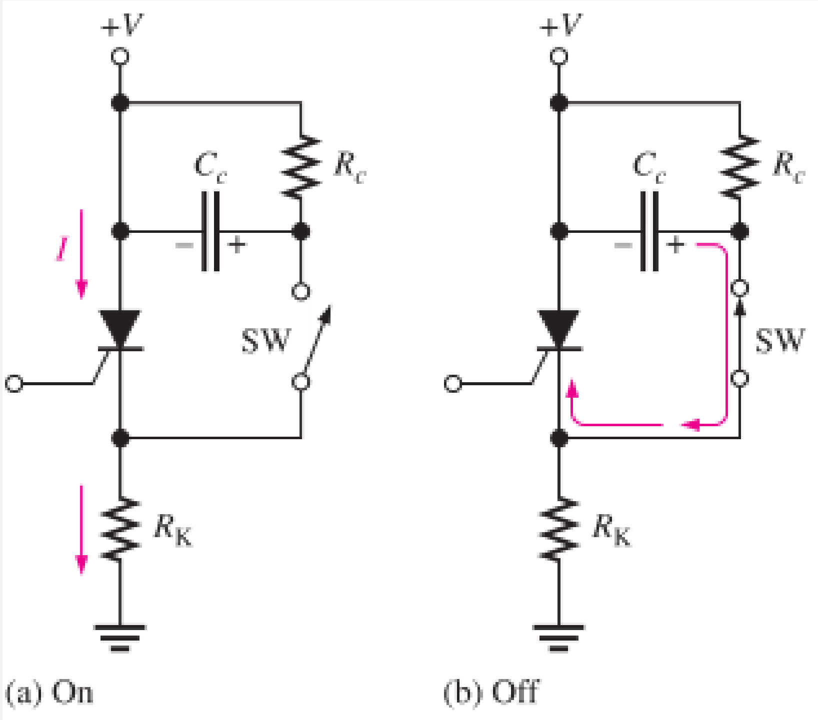
- Momentary series arrangement (**a**) – simply reduces the anode current to zero and causes the SCR to turn off
- Parallel switching arrangement (**b**) – routes part of the total current away from the SCR, thereby reducing the anode current to a value less than I_H.



TURNING THE SCR OFF

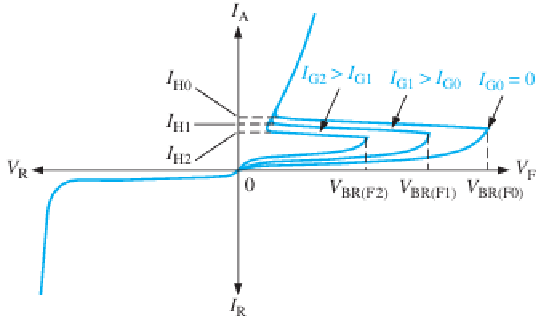
Forced Commutation

- Momentarily forcing current through SCR in the direction opposite to the forward-conduction → Net forward current is reduced below the holding value (I_H)
- The basic circuit consist of:
  - Transistor switch
  - Capacitor
- While SCR conducting the switch is open and C_c is charged to supply voltage through R_c (**a**)
- To turn off the SCR
  - Switch is closed
  - Placing the capacitor across the SCR and forcing current through it opposite to the forward current (**b**)
  - Takes few microseconds up to 30 μs



SCR CHARACTERISTICS AND RATING

- **Forward-breakover voltage $V_{BR(F)}$**
  - Voltage at which the SCR enters the forward-conduction region
  - $V_{BR(F)}$ is maximum when $I_G = 0$ and is designated $V_{BR(F0)}$
  - When the gate current is increased, $V_{BR(F)}$ decreases and is designed $V_{BR(F1)}$, $V_{BR(F2)}$ and so on, for increasing steps in gate current (I_{G1}, I_{G2} and so on)
- **Holding current I_H**
  - The value of anode current below which the SCR switches from forward-conduction region to the forward-blocking region
  - The value increases with decreasing values of I_G and is maximum for $I_G = 0$



(b) For various I_G values

SCR CHARACTERISTICS AND RATING

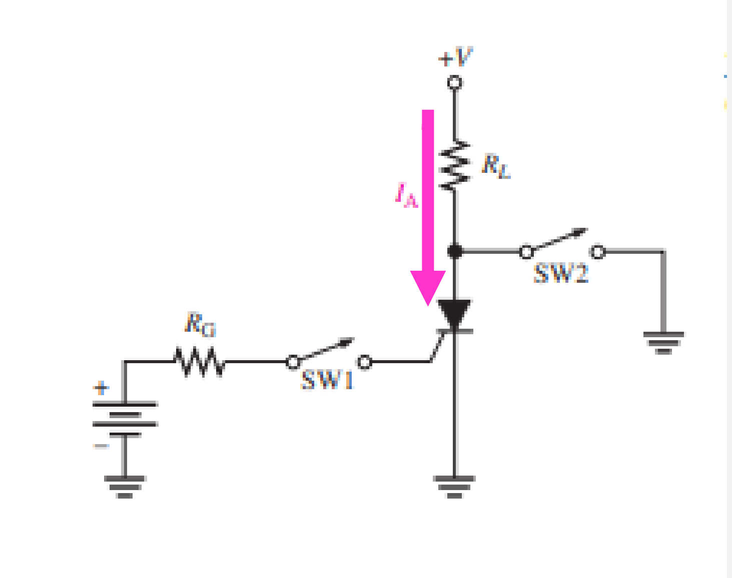
- **Gate trigger current** I_{GT}
  - The value of gate current necessary to switch the SCR from the forward-blocking region to the forward-conduction region under specified conditions.
- **Average Forward current** $I_{F(AVG)}$
  - The maximum continuous anode current (DC) that the device can withstand in the conduction state under specified conditions.

SCR CHARACTERISTICS AND RATING

- **Forward-blocking and reverse-blocking region**
  - These regions correspond to the *off* condition of the SCR where the forward current from anode to cathode is blocked by the effective open circuit of the SCR
- **Reverse breakdown voltage ($V_{BR(F)}$)**
  - This parameter specifies the value of reverse voltage from cathode to anode at which the device breaks into the avalanche region and begins to conduct heavily (the same as in a ***pn*** junction diode).
- **Forward-conduction region**
  - This region corresponds to the *on* condition of the SCR where there is forward current from anode to cathode through the very low resistance (approximate short) of the SCR.

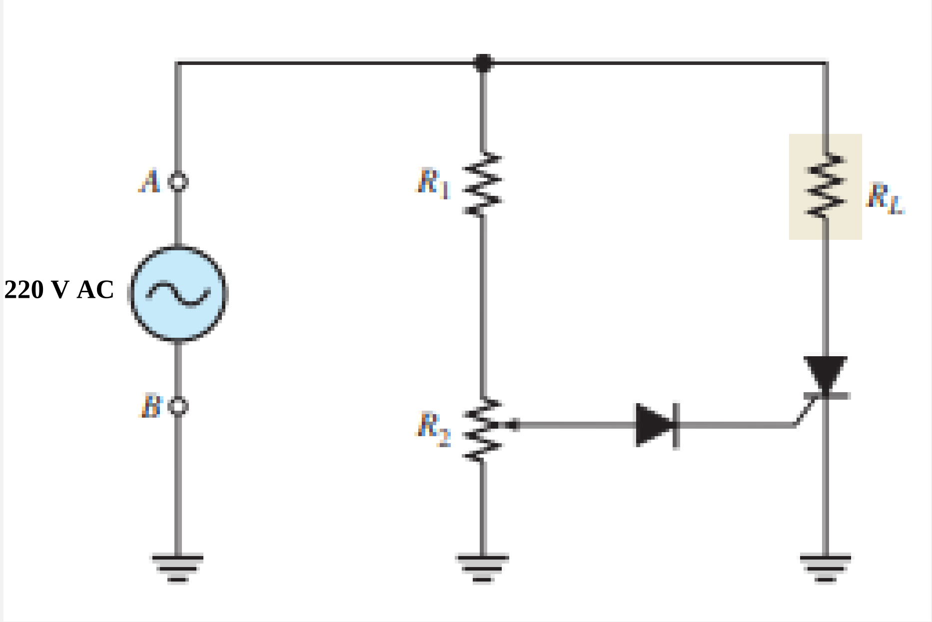
SCR APPLICATIONS
ON-OFF CONTROL OF CURRENT

- Permits current to be switched to a load by the momentary closure of switch SW1 and removed from the load by the momentary closure of switch SW2.
- Assuming the SCR is initially off, momentary closure of SW1 provides a pulse of current out of the gate, thus triggering the SCR **on**, so that it conducts current through R_L.
- The SCR remains in conduction even after the momentary contact of SW1 is removed if the anode current is equal to or greater than the holding current, I_H.
- When SW2 is momentarily closed, current is shunted around the SCR, thus reducing its anode current below the holding value, I_H. → This turns the SCR **off** and reduces the load current to zero.



SCR APPLICATIONS
HALF-WAVE POWER CONTROL

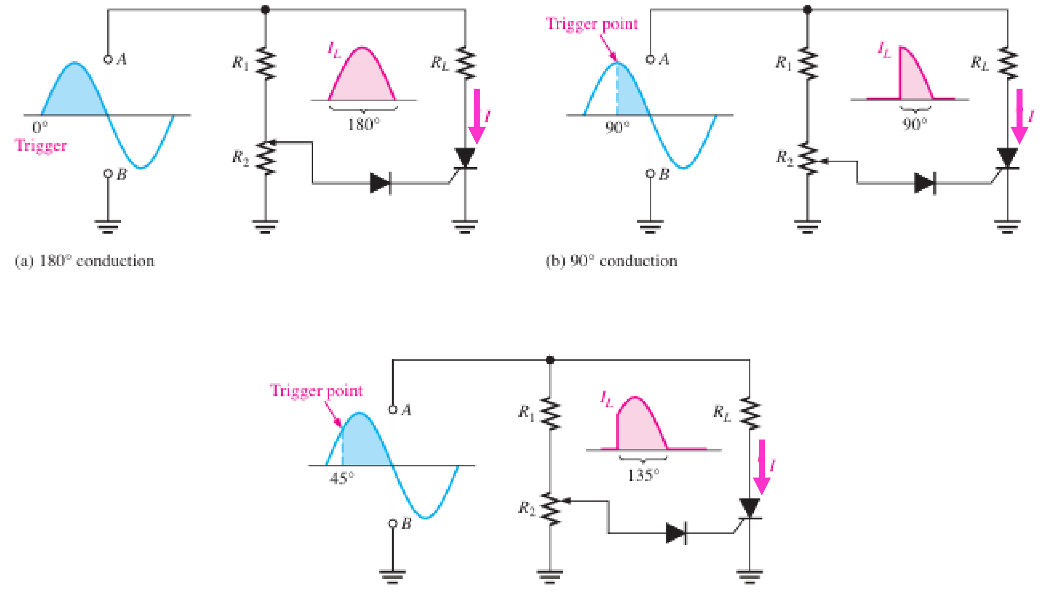
- Control of AC power for lamp dimmers, electric heaters and electric motors
- R_L represents the resistance of the load
- Resistor R_1 limits the current, and potentiometer R_2 sets the trigger level for the SCR
- By adjusting R_2, the SCR can be made to trigger at any point on the positive half-cycle of the AC waveform between 0° and 90°.



Half-wave, variable-resistance, phase-control circuit

SCR APPLICATIONS
HALF-WAVE POWER CONTROL

- When the SCR triggers near the beginning of the cycle (approximately 0°), it conducts for approximately 180° and maximum power is delivered to the load.
- When it triggers near the peak of the positive half-cycle (90°), the SCR conducts for approximately 90° and less power is delivered to the load.
- By adjusting R_2 triggering can be made to occur anywhere between these two extremes, and therefore, a variable amount of power can be delivered to the load.
- Triggering at the 45° point:
  - – When the AC input goes negative, the SCR turns off and does not conduct again until the trigger point on the next positive half-cycle. The diode prevents the negative AC voltage from being applied to the gate of the SCR



(a) 180° conduction
(b) 90° conduction
(c) 135° conduction

SCR APPLICATIONS
OVER-VOLTAGE PROTECTION

- The DC output voltage from the regulator is monitored by the Zener diode (D_1) and the resistive voltage divider (R_1 and R_2) .
- The upper limit of the output voltage is set by the zener voltage.
- If this voltage is exceeded, the zener conducts and the voltage divider produces an SCR trigger voltage.
- The trigger voltage turns on the SCR, which is connected across the line voltage.
- The SCR current causes the fuse to blow, thus disconnecting the line voltage from the power supply.